

# PEP4 Program at LBNL&SLAC

## Participation in the Electron-Positron Colliding Experiment (PEP-4) at SLAC-PEP and Development of New Detection and Data Handling Technology

### Spokespersons

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UNITED STATES:

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### Participating Groups

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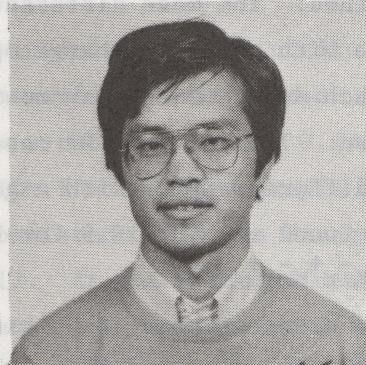
Univ. of Tokyo and INS  
(Univ. of Tokyo)

UNITED STATES:

LBL (Univ. of California),  
UCLA, Yale, UC Riverside,  
Johns Hopkins and others.

HEAVY QUARK PRODUCTION IN  $e^+ e^-$  ANNIHILATION AT 29 GeV

Hiroaki Aihara  
University of Tokyo, Tokyo 113, Japan  
(Representing PEP-4 TPC Collaboration)



Moriond 1985

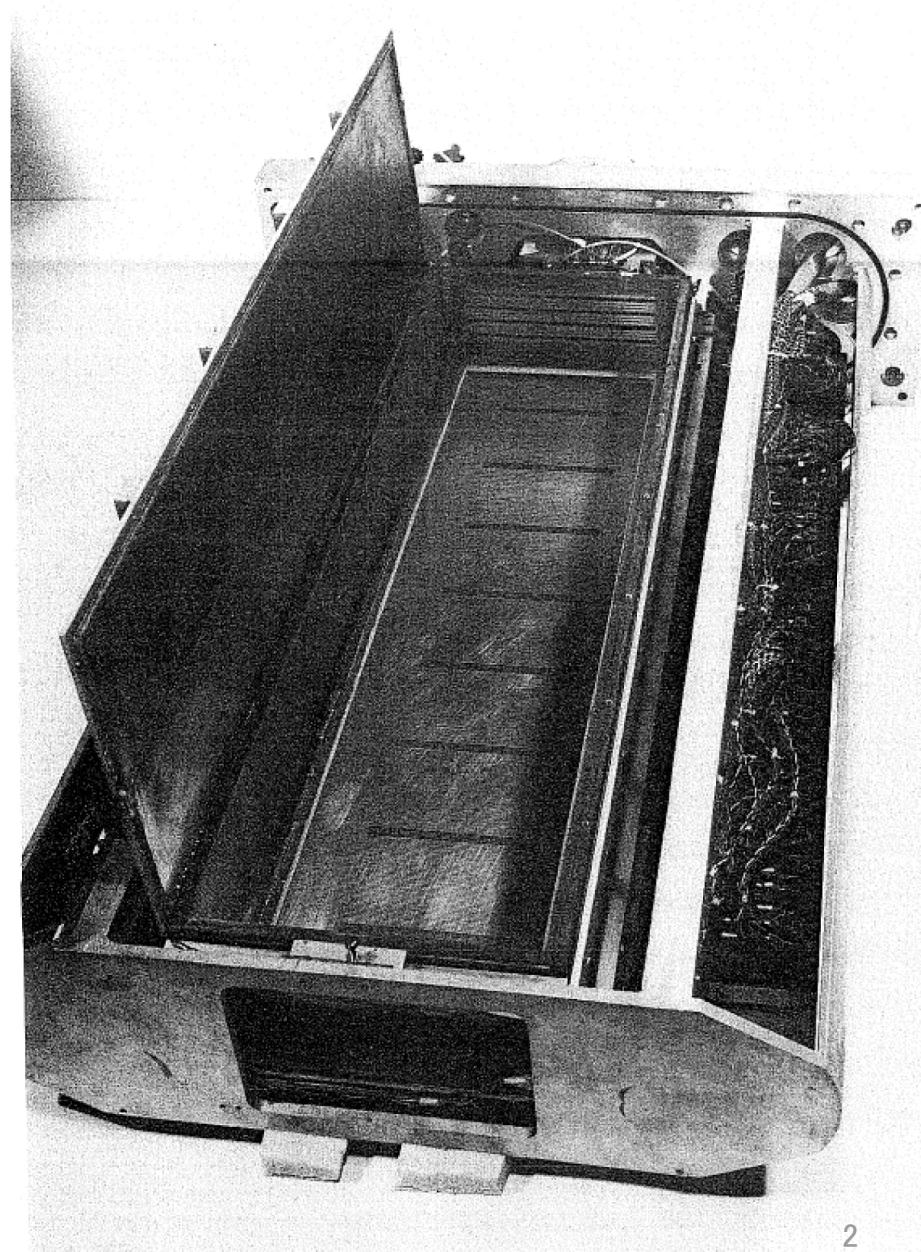
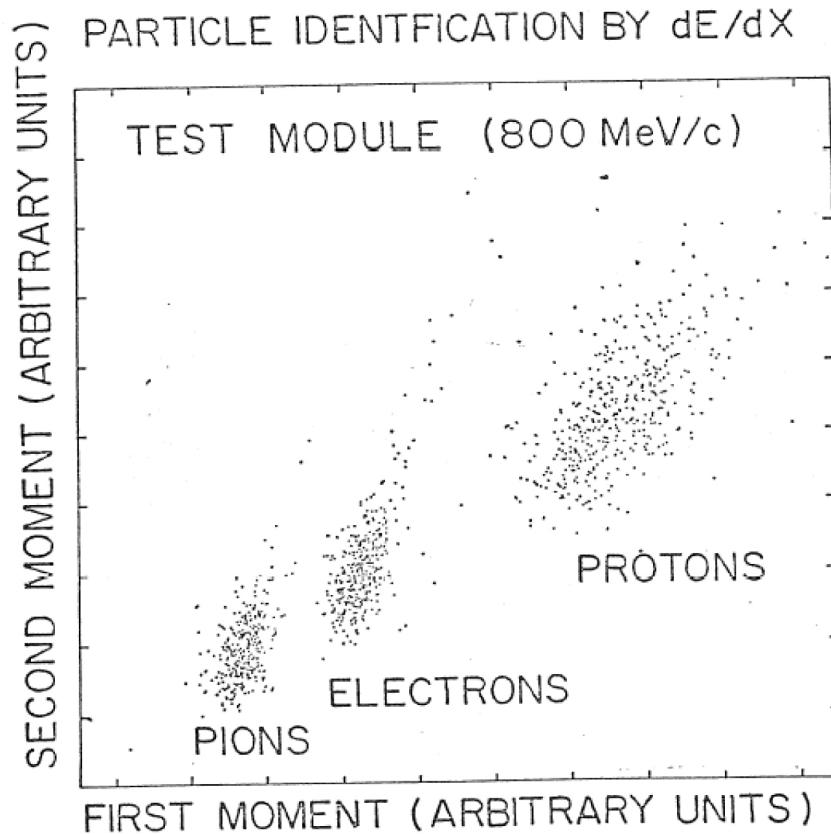
We present comprehensive studies on heavy quark production in  $e^+ e^-$  annihilations using the PEP-4 TPC detector. The results include the measurements of  $b$  and  $c$  quark fragmentation functions and of the forward-backward asymmetries in  $e^+ e^- \rightarrow c\bar{c}$  and  $b\bar{b}$ , based on  $D^*$  and prompt lepton events. We have observed  $F^*$  meson via its radiative decay  $F^* \rightarrow \gamma F$  followed by  $F \rightarrow K\bar{K}\pi$ . Gluon emission from  $b$  quark is investigated using  $b$  quark events tagged by prompt leptons.

The US/Japan Collaboration in High Energy Physics: The 30<sup>th</sup> Anniversary Symposium  
October 20-21, 2010 Kailua-Kona, Hawaii

# Bevatron Prototype TPC

-24-

## Time Projection Chamber



## Abstract

We present here some results obtained with the LBL Time Projection Chamber (TPC)<sup>1</sup> regarding the particle identification by the measurement of the ionization losses in the relativistic rise region. This includes the method of calibration using <sup>55</sup>Fe sources, the measurement of the resolution using cosmic rays, which shows an equivalent K- $\pi$  separation of 4.8 standard deviations at 3.5 GeV/c, and the preliminary results obtained with multihadronic events from  $e^+e^-$  annihilations.

## Introduction

The PEP-4 facility<sup>2</sup> is a large colliding beam detector installed since January 1982 at the PEP electron positron machine at the Stanford Linear Accelerator Center (SLAC). The central detector in PEP-4 is a Time Projection Chamber (TPC), a large volume drift chamber which uses ionization loss measurement to identify particles. In the standard operating conditions, the 2 meter long, 2 meter diameter cylindrical chamber is filled with 8.5 atmospheres of a mixture of 80 % Argon and 20 % Methane [Figure 1]. The electrons liberated by the ionization drift at a speed of about 5 cm/ $\mu$ s toward one or the other end plane under the action of a 75 kV/m uniform electric field. The detector plane at

## TIME PROJECTION CHAMBER

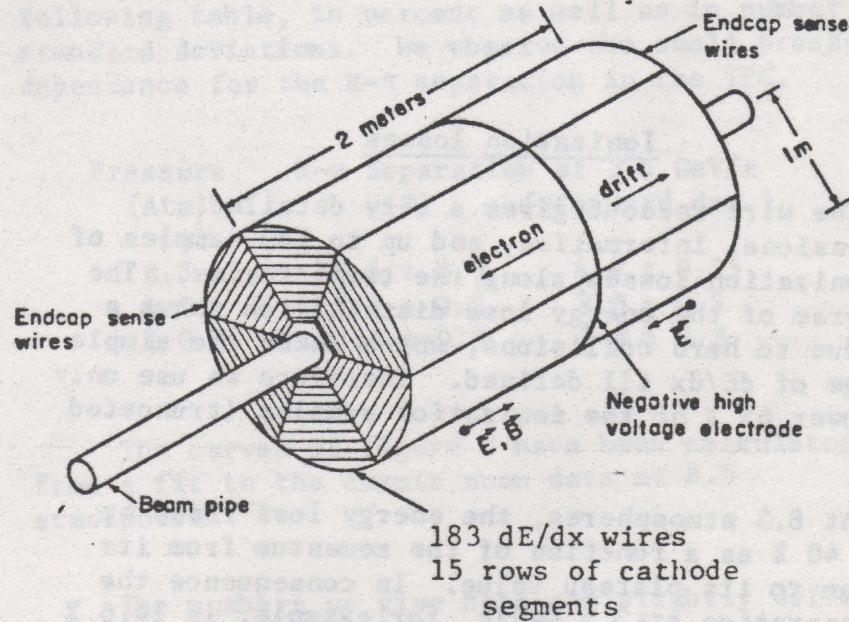


Fig. 1. A schematic drawing of the TPC

each end is divided into six sectors, covered with 183 wires, whose pulse heights are used to measure track ionization. The drift region and the wire amplification region are separated by a grid.

MEASUREMENT OF IONIZATION LOSS IN THE RELATIVISTIC RISE  
REGION WITH THE TIME PROJECTION CHAMBER\*

TPC-LBL-82-76

Presented by Bernard Gabioud<sup>1</sup>

at IEEE Meeting, Washington, D.C., 20 October, 1982

PEP-4 TPC Collaboration

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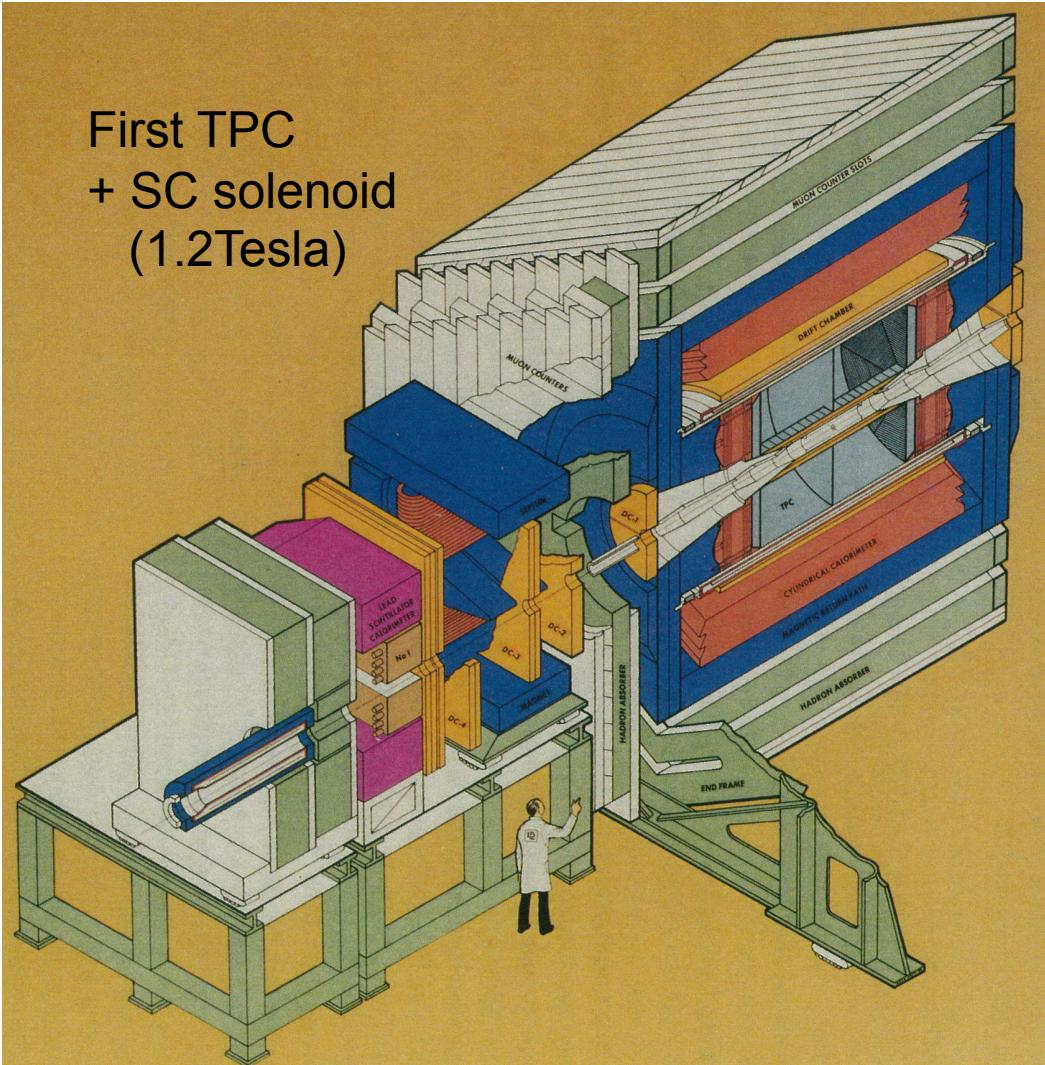
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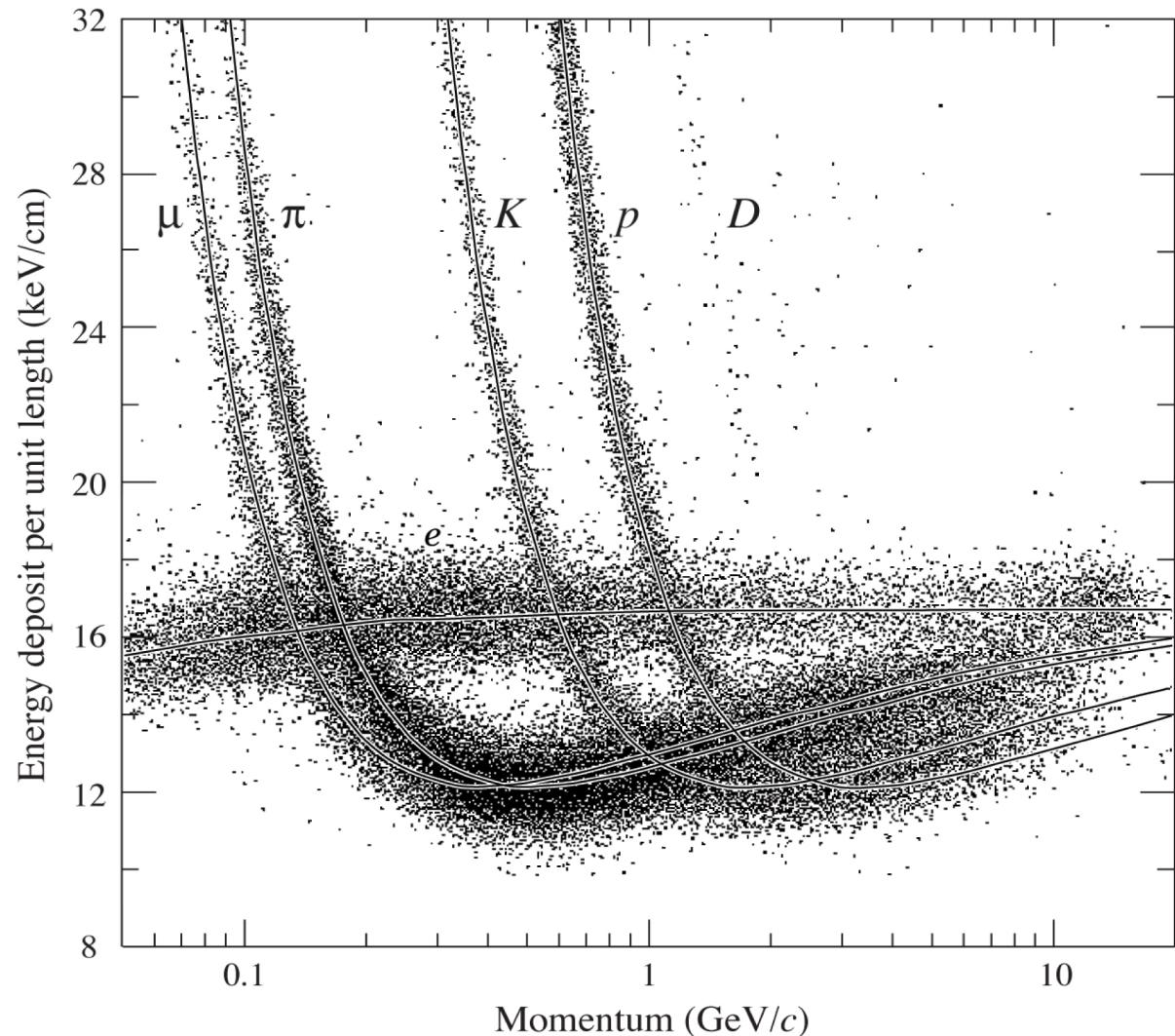
First TPC  
+ SC solenoid  
(1.2Tesla)



Dave Nygren (LBL) & Fred Catania (SLAC)

**PEP4/9-TPC** energy-deposit  
measurements (185 samples  
@8.5 atm Ar-CH<sub>4</sub> 80-20%)

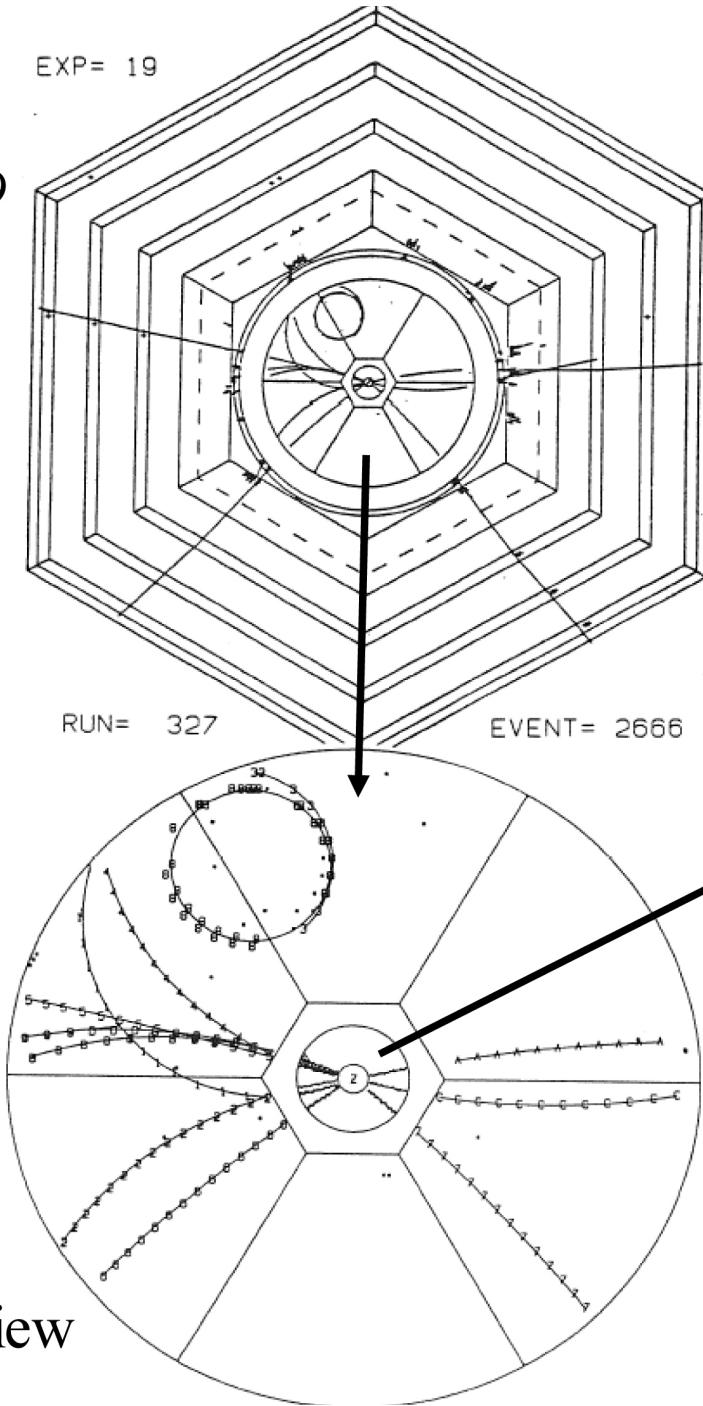
Electrons reach a Fermi plateau value of 1.4 times min. ionization. Muons from pion decays are separated from pions at low momentum;  $\pi$ /K are separated over all momenta except in the cross-over region. (Low-momentum protons and deuterons originate from hadron-nucleus collisions in inner materials such as the beam pipe.)



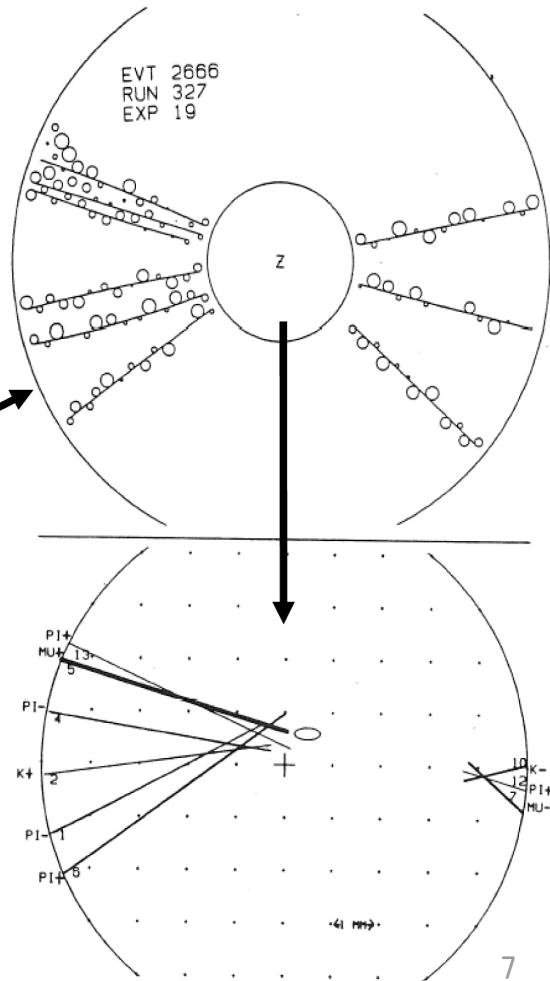
dE/dE resolution ~4%

# B Physics

One event from PEP4/9  
commissioning run in  
1989.



Straw tube Vertex Chamber



## First Digital EM Calorimeter based on Geiger-mode chamber

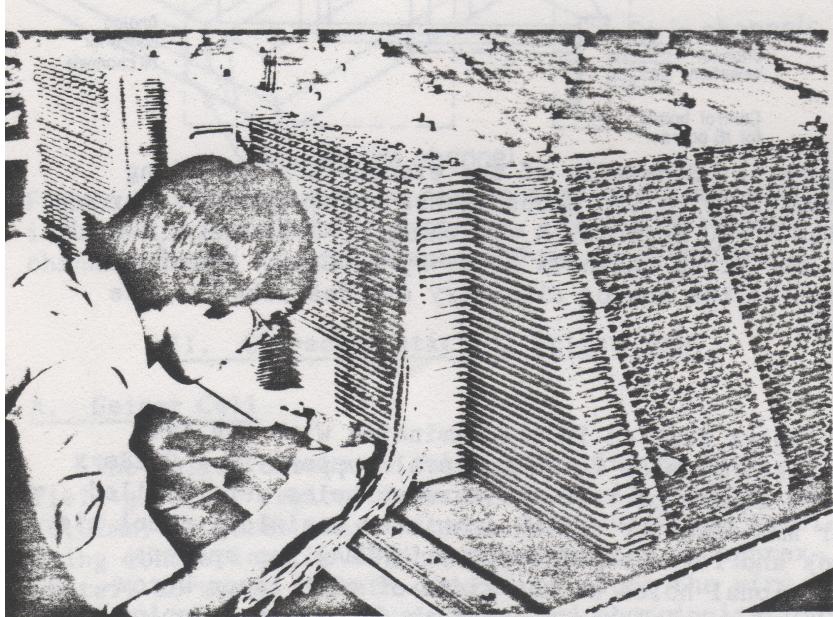


Figure 7. Photograph of partially assembled module showing laminated structure, tie rods and wiring. Details are given in the text.

After all layers were stacked the tie rods were inserted and tightened. Internal wiring for both sense wire and cathode strip channels (Figure 7) was carried out using wire-wrap techniques. Short cables bring all channel signals to the end bulkheads, where gas-tight connectors in slots provide for external high voltage and signal-cable connections to the module. 3mm-thick gasketed aluminum panels on the sides and top complete the gas enclosure.

### E. Electronics

Figure 6 shows schematically the analog electronics and the electrical connections to the sense wire channels. For the cathode strip channels the connections are direct, and trimming capacitors are needed in the corners of the modules. The 50 ohm

distribution of a typical anode channel triggered on almost anything. The spacing of successive numbers of cell discharges determines relative values for the low energy slope of the energy scale.

For the cathode-strip channels discrete pulse heights are not available. Instead, relative channel sensitivities are inferred by relating measured average pulse heights to those of the calibrated anode channels looking at the same events. Figure 9 shows preliminary measurements illustrating the accuracy with which this can be done. The very broad pulse height spectrum for cosmic rays with a wide angular distribution gives an anode-cathode pulse height difference which is sharply peaked, a conse-

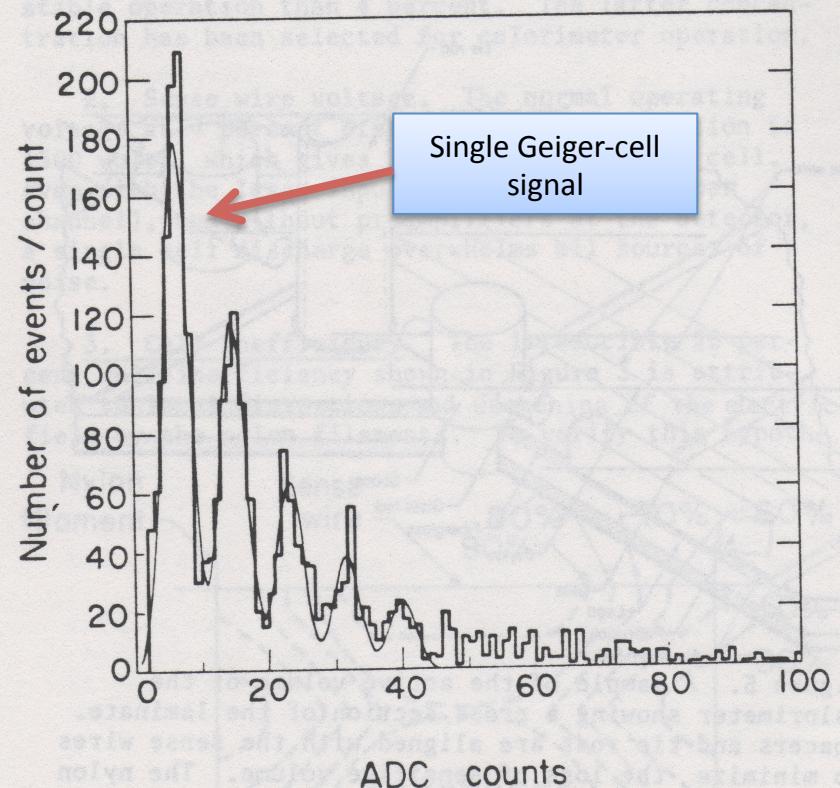


Figure 8. Pulse height spectrum for typical anode-

# Physics

- Hadron physics : hadronization (parton fragmentation), correlations, baryons,etc.  
(a la Werner Hofmann)
- Heavy quark physics: prompt leptons,  $D^*$ ,  
 $F^*(=Ds^*)$

## Observation of Strangeness Correlations in $e^+ e^-$ Annihilation at $\sqrt{s} = 29$ GeV

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Correlations in rapidity space are presented for identified  $\pi^\pm$  and  $K^\pm$  in  $e^+ e^-$  annihilation at 29-GeV c.m. energy. Short-range  $KK$  correlations indicate local flavor compensation in the hadronization process. Long-range  $KK$  and  $\pi\pi$  correlations prove that the initial partons carry flavor. In addition, we observe significant  $K\pi$  correlations as a result of heavy-quark decays.

PACS numbers: 13.65.+i

In standard models of hadronization the process  $e^+ e^- \rightarrow$  hadrons is governed by two distinct time scales. At early times, the production of a parton system is described by perturbative theory. On a much longer time scale, nonperturbative strong interactions transform these partons into hadrons. The large momentum scale involved in the creation of the initial  $q\bar{q}$  pair results in a large separation in phase space of hadrons containing those partons. Since the two primary quarks in an annihilation event carry opposite quantum numbers, this process will give rise to long-range flavor correlations (LRC). Such studies by previous experiments have indeed provided evidence that the primary partons are charged.<sup>1,2</sup> On the other hand, the final formation of hadrons is usually assumed to be governed by small- $Q^2$  phenomena which generate local, short-range correlations (SRC) (see Fig. 1).

In this paper we examine these two regimes by studying flavor correlation in multihadron events, with special emphasis on the investigation of strangeness correlations. As a result of the small number of strange quarks produced in a typical event, strangeness is a much cleaner way to label a specific  $q\bar{q}$  pair than, for example, charge.

The data used in this analysis were collected by the time-projection-chamber (TPC) detector at the PEP storage ring and consist of 23 650 annihilation events, representing  $68 \text{ pb}^{-1}$  at 29-GeV c.m. energy. The PEP4 facility and the multihadronic event selection have been described previously.<sup>3</sup> The TPC provides both tracking information and charged-particle identification. The detector has a

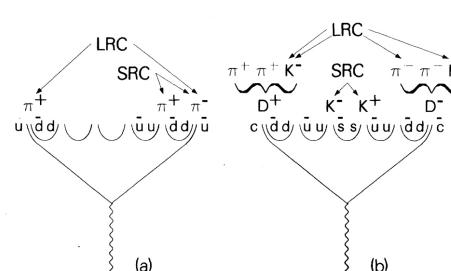


FIG. 1. The mechanisms responsible for long- and short-range flavor correlations (a) among pions and (b) between kaons and pions.

## Evidence of soft and collinear gluon emission in $e^+ e^-$ hadronic events

TPC/Two-Gamma Collaboration

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**Abstract.** In the study of rapidity distributions of charged pions produced in  $e^+ e^-$  annihilation at 29 GeV, we observe a significant dip in the rapidity distributions at  $y \approx 0$  for events with low sphericity. A comparison of data with several QCD-based phenomenological models strongly suggests that this structure is related to the emission of multiple soft and/or collinear gluons.

### 1 Introduction

Although quantum chromodynamics (QCD) is believed to be the fundamental theory of hadronic processes, no prescription currently exists for calculating physical hadronic amplitudes. Comparisons of theoretical predictions and experimental measurements

usually involve phenomenological models of QCD [1]. In these models, an initial parton configuration is created by the  $e^+ e^-$  annihilation photon. These partons, which typically are initially highly virtual (i.e. far off their mass shell), cascade down in mass via successive emission of gluons, initiating a quark-gluon shower analogous to an electromagnetic shower. Finally, the partons in the shower rearrange somehow to form color singlet hadrons. The actual models are formulated in two steps: first, a configuration of partons is determined based on QCD perturbation theory; next, the formation of hadrons from those partons is described by a phenomenological model. The two regimes are separated by a rather arbitrary cutoff either in the parton virtuality or in the minimum two-parton invariant mass.

In the description of  $e^+ e^-$  annihilation reactions, two alternative schemes for the perturbative QCD

## Prompt Electron Production in $e^+e^-$ Annihilations at 29 GeV

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**Abstract.** We have measured the inclusive prompt electron cross section over a wide momentum range ( $P > 0.5$  GeV/c) with the PEP-4 TPC detector. The semielectronic branching fractions of the  $c$  and  $b$  quarks are  $(9.1 \pm 0.9(\text{stat.}) \pm 1.3(\text{syst.}))\%$  and  $(11.0 \pm 1.8 \pm 1.0)\%$ , respectively. The  $b$  quark fragmentation function peaks at high  $z$  with  $\langle z_b \rangle = 0.74 \pm 0.05 \pm 0.03$ . The axial couplings to the neutral current are  $a_c = 2.3 \pm 1.4 \pm 1.0$  for the  $c$  quark and  $a_b = -2.0 \pm 1.9 \pm 0.5$  for the  $b$  quark.

Prompt electrons serve as a clean signal of heavy ( $c$  and  $b$ ) quarks. The electron production rates and momentum spectra reflect the semielectronic branching fractions and energy spectra of the parent hadrons which contain the heavy quarks. The distribution of transverse momentum ( $P_T$ ) with respect to the thrust axis depends on the parent quark mass. This makes it possible to separate  $b$  quark events from  $c$  quark events. Using the charge of the prompt electron to distinguish quark jets from antiquark jets,

we can measure the forward-backward asymmetry in  $e^+e^-$  annihilations into quarks. In this paper we present the inclusive prompt electron cross sections, the  $c$  and  $b$  quark semielectronic branching fractions, the shape of the  $b$  quark fragmentation function and a measurement of the forward-backward asymmetry in  $e^+e^- \rightarrow c\bar{c}$  and  $b\bar{b}$ .

The data were collected with the PEP-4 TPC detector at PEP with an integrated luminosity of  $77 \text{ pb}^{-1}$  at center-of-mass energy 29 GeV. For the present analysis we selected events which satisfy  $|\cos \theta_T| < 0.7$  from the hadronic event sample described in [1]. Here  $\theta_T$  is the angle between the beam axis and the thrust axis determined by charged tracks. Electrons were identified by the Time Projection Chamber (TPC) [2] and the Hexagonal Calorimeter (HEX) [3].

The TPC identifies charged particles by measuring momentum and ionization loss ( $dE/dx$ ) simultaneously. The momentum resolution is  $(dP/P)^2 = (0.06)^2 + (0.035P)^2$  in a 4 kG axial magnetic field. The  $dE/dx$  resolution is 3.5–4% depending on the number of  $dE/dx$  samples available. Based on the

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Evidence for a narrow state decaying into an  $F$  meson and a photon has been obtained in  $e^+e^-$  annihilation events at 29-GeV c.m. energy. This state lies  $139.5 \pm 8.3(\text{stat.}) \pm 9.7(\text{syst.})$  MeV above the  $F$ -meson mass and is consistent with the expected  $F^*$  meson. The  $F$  mesons are identified by a peak in the  $K^+K^-K\pi^\pm$  mass at  $1.948 \pm 0.028 \pm 0.010$  GeV.

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The quark model predicts four ground-state charmed mesons<sup>1</sup>:  $D$ ,  $D^*$ ,  $F$ , and  $F^*$ . The first three of these are now well established,<sup>2–4</sup> and searches for the  $F^*$  have been conducted by several experiments,<sup>5</sup> with the first candidates reported recently.<sup>6</sup> According to the quark model, the  $F^*$  and the  $F$  are isosinglets and the  $F \rightarrow F\pi^0$  decay is forbidden leaving the radiative decay to the  $F$  as the only significant mode.

We report evidence for a narrow state that decays to an  $F$  meson and a monochromatic photon using data collected by the PEP-4 TPC detector at the PEP storage ring at SLAC. Our observation is based on 29095 hadronic events (corresponding to an integrated luminosity of  $77 \text{ pb}^{-1}$ ) produced in  $e^+e^-$  annihilation at  $E_{\text{c.m.}} = 29$  GeV.

In the PEP-4 detector,<sup>7</sup> momentum and ionization loss ( $dE/dx$ ) of charged particles are measured in a time projection chamber (TPC). In the TPC, the  $dE/dx$  value for each track is calculated from the pulse heights measured by anode wires of multiwire proportional chambers.<sup>8</sup> The average  $dE/dx$  resolution is 3.9% for tracks with at least thirty ionization samples. At a momentum of 5 GeV/c, typical for this analysis, the measured  $\pi$ - $K$  separation in  $dE/dx$  is 14%. The momentum resolution is

given by  $(dp/p)^2 \approx (0.06)^2 + (0.035p)^2$  ( $p$  in  $\text{GeV}/c$ ) for tracks in hadronic jets.

Photons are detected either by the hexagonal Geiger-mode calorimeter, or by the TPC as  $e^+e^-$  pairs arising from photon conversion. In the calorimeter the photon energy is measured to about  $16\%\sqrt{E}$  (rms with  $E$  in gigaelectronvolts) and nearby pairs of photons are resolved if the angle between them is greater than 60 mrad. Photons are accepted if their polar angle  $\theta$  is between  $50^\circ$  and  $130^\circ$  and if their energy is greater than 400 MeV in the calorimeter. Photons of any energy are accepted if they convert in front of the TPC, and the conversion pair is unambiguously identified. Of photons contained in the solid angle and energy range defined by the selection criteria, 41% are detected in the calorimeter and 8% are detected in the TPC as conversion pairs.

With the use of the measured momentum and  $dE/dx$ ,  $\chi^2$ 's are calculated for each track to be an electron ( $\chi_e^2$ ), a pion ( $\chi_\pi^2$ ), a kaon ( $\chi_K^2$ ), or a proton ( $\chi_p^2$ ). A particle is then "identified" as a kaon if (a) the number of good  $dE/dx$  sample points is 30 or more, (b)  $\chi_K^2 < 2.7$  (for one degree of freedom), and (c)  $\chi_K^2 < \chi_e^2, \chi_\pi^2, \chi_p^2$  if  $p < 2$  GeV or  $\chi_K^2 < \chi_e^2, \chi_\pi^2$  if  $p > 2$  GeV/c. A looser criterion,  $\chi_K^2 < 6.6$ , is

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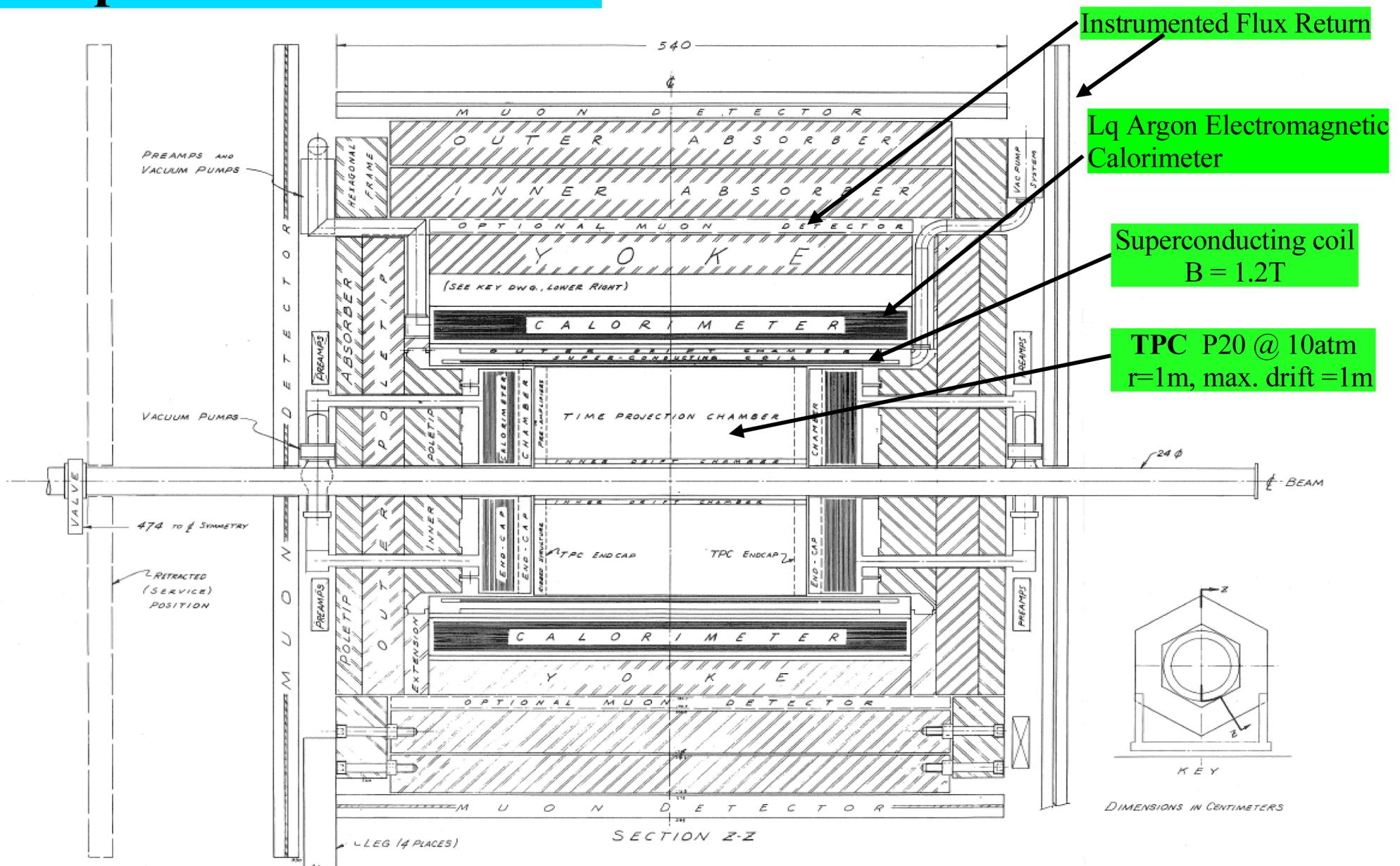
# Conclusion

- PEP4 pioneered many advanced detector technologies, TPC with CCD readout, thin SC detector solenoid, digital cal.
- Hadronization/charm and b physics
- PEP4 produced many leaders of HEP and outstanding PhDs.
- Great Success !



# Proposed TPC Detector

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XBL 7612-11403 15

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M.L. Stevenson<sup>1</sup>, D.H. Stork<sup>2</sup>, H.K. Ticho<sup>2</sup>, N. Toge<sup>5</sup>, M. Urban<sup>1</sup>, G.J. Van Dalen<sup>3</sup>, R. van Tyen<sup>1</sup>, H. Videau<sup>1</sup>,  
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### Abstract

We present here some results obtained with the LBL Time Projection Chamber (TPC)<sup>1</sup> regarding the particle identification by the measurement of the ionization losses in the relativistic rise region. This includes the method of calibration using  $^{55}\text{Fe}$  sources, the measurement of the resolution using cosmic rays, which shows an equivalent  $K-\pi$  separation of 4.8 standard deviations at 3.5 GeV/c, and the preliminary results obtained with multihadronic events from  $e^+e^-$  annihilations.

### Introduction

The PEP-4 facility<sup>2</sup> is a large colliding beam detector installed since January 1982 at the PEP electron positron machine at the Stanford Linear Accelerator Center (SLAC). The central detector in PEP-4 is a Time Projection Chamber (TPC), a large volume drift chamber which uses ionization loss measurement to identify particles. In the standard operating conditions, the 2 meter long, 2 meter diameter cylindrical chamber is filled with 8.5 atmospheres of a mixture of 80 % Argon and 20 % Methane [Figure 1]. The electrons liberated by the ionization drift at a speed of about 5 cm/ $\mu\text{s}$  toward one or the other end plane under the action of a 75 kV/m uniform electric field. The detector plane at

### TIME PROJECTION CHAMBER

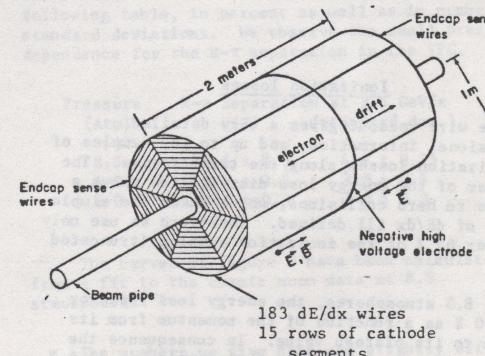


Fig. 1. A schematic drawing of the TPC

each end is divided into six sectors, covered with 183 wires, whose pulse heights are used to measure track ionization. The drift region and the wire amplification region are separated by a grid.